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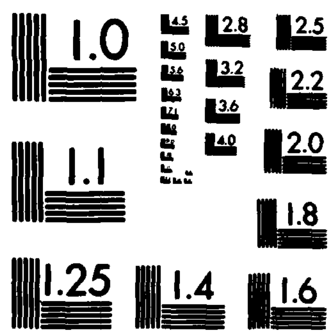
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Display Location of Verbal and Spatial Material: The Joint Effects of Task-Hemispheric Integrity and Processing Strategy

Christopher D. Wickens
Diane L. Sandry
Renady Hightower

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ERRATUM For SANDRY & WICKENS

Technical Report EPL-82-1/ONR-82-1

The following corrections should be made:

1. Figure 2,3,4. Legand across the abscissa should read:

   A/S V/S A/M V/M

   I/O Modalities

2. Pg. 39, item 3, line 6 - should refer to Figure 18, rather than Figure 17.

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In this experiment 10 subjects controlled a first or second order system while monitoring a visual channel for one or two 3-character alpha-numeric call numbers in a memory search task. In a compatible display configuration the tracking task was displayed to the left visual field and controlled by the left hand. The verbal task was performed on the right. Compatibility was achieved here because the spatial tracking display had direct access to the processing hemisphere, which also directly -

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The results of Experiment 1 indicated a strong main effect of compatibility for both tasks. This effect was consistent across all levels of difficulty of both tasks. In Experiment 2 only the most difficult tasks were performed in the two configurations and the emphasis between the two tasks was varied. Compatibility effects were again observed, and were enhanced when the verbal task was emphasized. These results are interpreted in terms of scanning strategies adopted by the subjects. The implications of the results of both experiments to the design of complex displays are discussed. They suggest that when several sources of verbal and spatial or analog information are displayed in parallel, for either monitoring or control, analog information should be displayed to the left of verbal information.

Display Location of Verbal and Spatial Material: The Joint Effects of Task-hemispheric Integrity and Processing Strategy

Christopher D. Wickens, Diane Sandry, and Renady Hightower

Abstract

In this experiment 10 subjects controlled a first or second order system while monitoring a visual channel for one or two 3-character alpha-numeric call numbers in a memory search task. In a compatible display configuration the tracking task was displayed to the left visual field and controlled by the left hand. The verbal task was performed on the right. Compatibility was achieved here because the spatial tracking display had direct access to the processing hemisphere, which also directly controls the manual response; a corresponding assignment guides the verbal task. In the incompatible configuration, the two tasks are reversed: tracking to the right, verbal memory to the left.

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Introduction

Computer-generated displays in today's advanced aircraft present a wide variety of analog and verbal information to the pilot. The computer-based logic behind such displays furthermore allows for a great degree of flexibility concerning where different elements may be placed. The particular concern of this report is whether differences in the efficiency of information processing across the visual field should dictate the placement of verbal and analog material.

There are at least three possible principles that should govern information placement: 1) Information that is important should be placed centrally or to the top and left of displays. 2) Information that entails a high level of static acuity (e.g., reading print) should be located in such a way that it can readily access foveal vision. 3) If information must be peripherally located, then information that is analog or spatial in nature will be better processed to the left of fixation. Information that is verbal will be better processed to the right. The principle of this last assertion is the focus of the current report.

There has by now accumulated a reasonably large volume of experimental evidence to support this assertion which states that material of a given class (spatial or verbal) will be processed most efficiently if it is provided direct access to the hemisphere of most efficient processing. The structure of the nervous system is such that information delivered on a given side of the body will directly access the contralateral hemisphere. This delivery may be either in terms of visual field, or of ears. Stimulus material with right visual field left hemisphere (RVF-LH) superiority are typically those involving words, phonetic judgments, linguistic processing, or discriminations of high spatial or temporal frequency. Stimuli with left visual field-right hemispheric (LVF-RH) superiority are more typically those involving spatial or analog judgments, judgments of low spatial frequency, and more "global" perceptions. These contrasts have recently been summarized by Moscovitch (1978), Nebes (1976), Sargent (1982), Friedman & Polson (1981), and Friedman, Polson, Gaskill, and Defano (1982). We shall refer to this as principle (1), <u>the direct access principle</u>.

In order to consider the issue of display lateralization within the context of human engineering it is necessary to address the issue of dual task processing. This is because, in a single task environment, there would be no reason for the operator to fixate anywhere else but an area in which the displayed information is foveal. In this case visual information accesses both hemispheres directly and so there is no differential processing. Thus we are concerned here instead with situations in which the operator should optimally be extracting information from two display locations in parallel only one of which can be foveal at a time. This may involve the tracking of two analog quantities, the tracking of one, while monitoring another, or the reading of more precise alpha-numeric information, while either monitoring or tracking an analog variable. When the issue of dual task

processing of spatial and verbal material is introduced, three further phenomena in addition to the direct access principle are relevant: resource competition between codes, competition within a task, and task-hemispheric integrity. Each of these will now be described.

(2) Resource-competition between codes. There is by now an ample body of evidence to suggest that two tasks demanding different codes of perception and central processing (i.e., verbal and spatial) will be time-shared more efficiently than two tasks demanding common codes (i.e, two verbal tasks or two spatial tasks; Wickens, 1980). This difference is notable whether the stages of processing involved are perceptual (e.g., Sandry, Wickens, & Micalizzi, 1981; Moscovitch & Klein, 1978), central processing and working memory (Isreal, 1980; Baddeley & Leiberman, 1978; Weingartner, 1982; Sandry & Wickens, 1982), or response (Vidulich & Wickens, 1981; Brooks, 1966, 1967; Hicks, 1975; McFarland & Ashton, 1976).

(3) Resource competition within a task. A number of investigations have suggested that a given task configured in such a way that both central processing and response elements are carried out within a given hemisphere, will be performed less efficiently than when those elements are distributed across hemispheres (e.g., Kinsbourne & Hicks, 1978; McFarland & Ashton, 1976). For example, Wickens and Sandry (in press) found that as the central processing demands of the verbal memory search task were increased, assumed to impose greater load on left hemispheric processing, performance with the right hand responding (using the common hemisphere to control the response) deteriorated faster than performance with left handed responding (using the separate hemisphere). When a spatial memory search task was employed instead, the direction of this interaction between task load and hand reversed.

(4) Task-hemispheric integrity. The preceding principle would suggest that within-task competition will be minimized if the processing and response functions are carried out in different hemispheres. However, Wickens and Sandry (in press) point out that under dual task conditions, when a spatial and verbal task are time-shared and all processing is fully utilized no matter which configuration is used, optimal time-sharing will occur when the handedness pairing is reversed. That is, when the processing and response functions of each task are carried out within the same hemisphere. This configuration which Wickens and Sandry label as one of "task-hemispheric integrity", is advantageous because it assigns each hemisphere exclusive responsibility for one task (Wickens, Mountford, & Schreiner, 1981). As such, there is no need for any "bookkeeping" operations in which a given hemisphere must perform the processing associated with one task and response functions associated with the other.

While both Wickens, Mountford, and Schreiner (1981) and Wickens and Sandry (in press) obtained experimental data supporting the concept of task hemispheric integrity, the effects observed in these investigations were not strong. In particular, the differences between integrity and non-integrity assignments were small enough as to be of questionable importance as a guideline for system design. One potential reason for the reduced magnitude of this effect is that the displays of both tasks in a time-shared pair were foveal. As a consequence, neither task benefitted from the direct access principle described above. Furthermore, both tasks were quite simple in their information processing demands. In Wickens and Sandry's investigation the tracking task was first order, and the memory search task required only two letters to be held in short term memory. Wickens, Mountford, and Schreiner employed a critical instability tracking task and a letter categorization task. The relative ease of performance of both of these tasks might have allowed both to be performed well independent of hand assignment.

The purpose of the present experiment was to investigate the combined effects of display location (influencing direct access) and response assignment (influencing task hemispheric integrity) when a spatial and verbal task of greater difficulty are time-shared. In the present experiment the two variables covaried. That is, when the spatial task is displayed to the left and the verbal to the right, thus conforming to the direct access principle, the spatial task is also responded with the left hand and the verbal with the right conforming to the task hemispheric integrity principle. We refer to this as a compatible configuration. Conversely, when the display is switched, so also is the response hand. This is the incompatible configuration. Although it would in theory be possible to manipulate display and response location orthogonally, the two additional conditions thus created would make little sense from a human engineering standpoint. This is because those conditions would generate a strong degree of stimuli-response incompatibility (Fitts & Seeger, 1953). A task displayed on one side would be responded to with the contralateral hand. Under the assumption that such design configurations should be avoided, they were excluded from our experiment.

Although there exists by now a relatively substantial data base on performance with parafoveal displays, the explicit data concerning lateralized performance with spatial and verbal tasks that are typical of the operational environment are far fewer. Two investigations however provided some tentative support for the direct access principle. Levison, Elkind, and Ward (1971) performed an extensive series of investigations on foveal and parafoveal tracking of single and multiaxis tasks. Of greatest relevance to the current issue was the conclusions drawn from conditions in which four separate displays, located in a square array were to be tracked using two 2-axis controls. They found best performance (on all four axes) when the display to the upper right was fixated, and poorest performance when fixation was to the lower left. The relevance of these findings is that in the former condition, those tracking displays in the periphery are delivered to the left visual field (direct access for a spatial task), while in the

latter condition peripheral displays are to the right (indirect access). The importance of this effect is emphasized in its magnitude. Total tracking error was roughly 50% greater in the incompatible condition. Furthermore, Levison et al. found that when subjects were given the opportunity to fixate the four axis display as they pleased, roughly 47% of the time was spent fixating the upper right and only 13% in the lower left. Subjects, in other words, optimally selected that fixation strategy that allowed them to use the direct access principle.

An investigation by Casey, Brightmaier, and Nason (1977) also provides converging support for direct access with spatial displays. Their subjects performed a primary tracking task on a flight simulator and a secondary spatial monitoring task (ensuring that two engine operating levels were maintained within critical bounds). Two display configurations were compared. One in which the secondary task was to the left of the primary and one in which it was to the right. Since it was assumed that subjects would generally fixate the primary task, the former condition provided direct access for the secondary task, the latter did not. Casey et al. found that when performance on the two tasks was combined, reliably superior performance was generated in the direct access condition.

In the present experiments then we investigate the direct access principle with a spatial (tracking) and a verbal (memory search) task, each of varying complexity. In Experiment 1, we compare performance in the condition in which direct access and task hemispheric integrity are confirmed (compatible) with the condition in which they are not (incompatible). Unlike the experiments of Casey et al. and Levison et al., no effort is made to control for task primacy in Experiment 1 either directly or by control of fixation. Our effort was to determine if the effects would emerge under conditions in which subjects viewed each task as equally important. We felt that control of fixation would be unrealistic of real task environments. In Experiment 2 we again manipulated compatibility but also task primacy, while holding task difficulty at a constant level.

Method

Subjects. Ten right handed male subjects were paid $3.00/hr plus bonus for their participation in the experiment. All subjects took the Bryden handedness questionnaire (Bryden, 1977) and all scored as high as right handers.

Apparatus. Both tasks were displayed on a Hewlett Packard 1300 display and both were controlled by a PDP 11/40 computer. Subjects manipulated a MSI 421 joystick in the fore aft direction to control the tracking task. Responses for the memory search task indicated by depressing one of two buttons on a keyboard with the index or middle finger. Two controls attached to armrests on the subject's chair could be readily switched between conditions. The total display area subtended a visual angle of $4^{o} \times 3^{o}$. The 3-item characters used in the memory seach task subtended a visual angle of 30' x 10'.

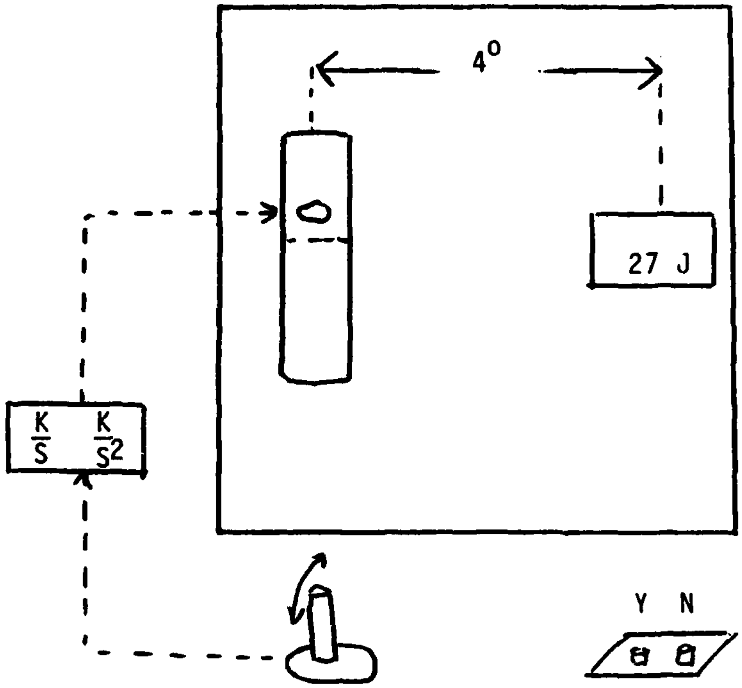
Tasks. The subjects' goal in the one axis compensatory tracking task, shown to the left of Figure 1a, was to maintain the vertically moving error cursor superimposed on the horizontal reference indicator. In addition to inputs from his control stick, the cursor was displaced by a band limited random disturbance input with an upper cutoff frequency of 0.32 Hz. The control dynamics of the task were of either first or second order, a variable manipulated between conditions.

In the memory search task, shown to the right of Figure 1a, the subjects' task was to decide, as rapidly as possible, if each of the series of three-character alpha-numeric stimuli belonged to a "positive set" of such stimuli, presented at the beginning of each tracking trial for encoding, and held in working memory for the duration of the trial. This memory set was either one character (e.g., 27J), or two characters (e.g., 32P, 19Y), a factor varied between conditions. Prior to each trial, the subject was given 10 seconds to encode the memory set items. During the trial, stimuli were presented at random intervals of between 4 and 7 seconds. Subjects were requested to respond as rapidly as possible to the stimuli but to maintain their error rate at a low level. "Yes" responses were always indicated with the forefinger, "no" responses with the index finger.

On single task trials, each display (tracking or RT) was positioned in the center of the screen. On dual task trials, the stimuli were positioned as shown in *Figure* 1. The display separation (4^{o}) was great enough so that when the tracking task was fixated in foveal vision, it was nearly impossible to resolve the alpha-numeric characters in peripheral vision. The display in Figure 1a is compatible, conforming to the direct access principle. That in Figure 1b is incompatible. With each display configuration, the response device was positioned to the corresponding side. Subjects were instructed to emphasize each task equally, and the bonus system was such as to reward good performance on each. Trials were 2 minutes in duration.

Design. The experiment consisted of 5 sessions, each lasting approximately 2 hours. The first session was devoted totally to practice. A majority of these practice trials were dual task and contained the second order tracking task. Compatible and incompatible displays were equally represented. The following three days contained the experimental conditions of Experiment 1. There were a total of 8 different single task conditions. These consisted of the two levels of tracking difficulty (first and second order) and the two levels of memory search difficulty (N = 1, 2), each performed with each hand. Correspondingly, these single task conditions generated 8 dual task conditions. The easy and difficult versions of each task in combination generated four combinations. These four were replicated with compatible and with incompatible display placement. On each of the three experimental days of Experiment 1, these 16 trial types (8 single, 8 dual) were randomized and presented in two successive blocks for a total of 32 trials/day. In addition, the trials on each day were preceded by 2 warmup trials of the most difficult condition.

FIGURE 1: (a) Compatible Configuration



(b) Incompatible Configuration

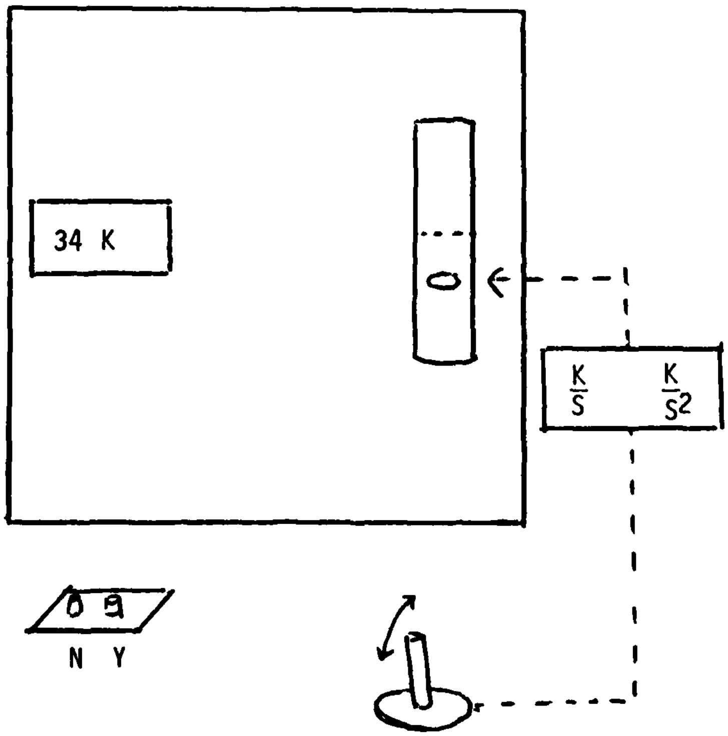


FIGURE 1: The two dual task displays; (a) compatible; (b) incompatible.

Results

Figure 2 presents the single task reaction time (left panel) and tracking (right panel) data. Each variable is shown as a function of the difficulty of the task, with hand as a parameter. It is clear that the memory search task was influenced by memory load. To verify this effect the RT data were submitted to a 4 way (hand x difficulty x day x replication) repeated measure ANOVA (Soupac Balanova). The effect of difficulty was significant ($F_{1,9} = 27.7$, $p < .001$), as was the interaction of hand and difficulty ($F_{1,9} = 7.37$, $p < .03$). As is evident from Figure 2, right hand performance suffers a greater loss due to increased difficulty than does left hand performance. This effect represents principle 3 outlined in the introduction: within-task resource competition, and replicates the previous finding of Wickens and Sandry (in press). There was no main effect of hand assignment ($F < 1$). There was also a reliable interaction of difficulty with day ($F_{2,18} = 6.33$, $p < .01$). This interaction reflects the greater improvement with practice of the more difficult version. No other interactions were significant (all p's > .10). The only reliable effect on errors was the effect of memory search difficulty ($F_{1,9} = 16.52$). Subjects made more errors in the difficult condition.

Tracking performance was also influenced by its own difficulty as the right hand panel of Figure 2 shows. Higher error was observed with second order tracking ($F_{1,9} = 84.9$, $p < .001$), while performance was also better with the right hand ($F_{1,9} = 6.9$, $p < .03$). The latter effect is anticipated because of the manual coordination imposed by the task, and the fact that the right hand was the dominant hand for all subjects. There was a weak interaction between hand and task ($F_{1,9} = 3.57$, $p = .08$). This interaction again is in the direction predicted by principle 2: a greater effect of difficulty when the hand of responding (left) is controlled by the same hemisphere as that assumed to be heavily engaged in performing the central processing aspects of the tracking task.

The dual task data are shown in Figure 3. The memory search data are shown on the top (Figure 3a) and the tracking data on the bottom (Figure 3b). The difference between the two lines within each panel represents the effect of compatibility of display placement. The effect of set size on the memory search task is portrayed by the two points connected by the line. Thus memory task difficulty is reflected by the slope of the lines. The two panels within each figure contrast the effect of increasing order of the tracking task on dual task performance.

The data reflect a marked effect of compatibility on performance. Across all panels, performance in the incompatible configuration is consistently poorer than the compatible. For RT performance this was indicated by a reliable main effect of compatibility ($F_{1,9} = 8.20$, $p < .02$). In addition, the effect of set size significantly increased dual task reaction time ($F_{1,9} = 42.5$, $p < .001$). Tracking difficulty

FIGURE 2

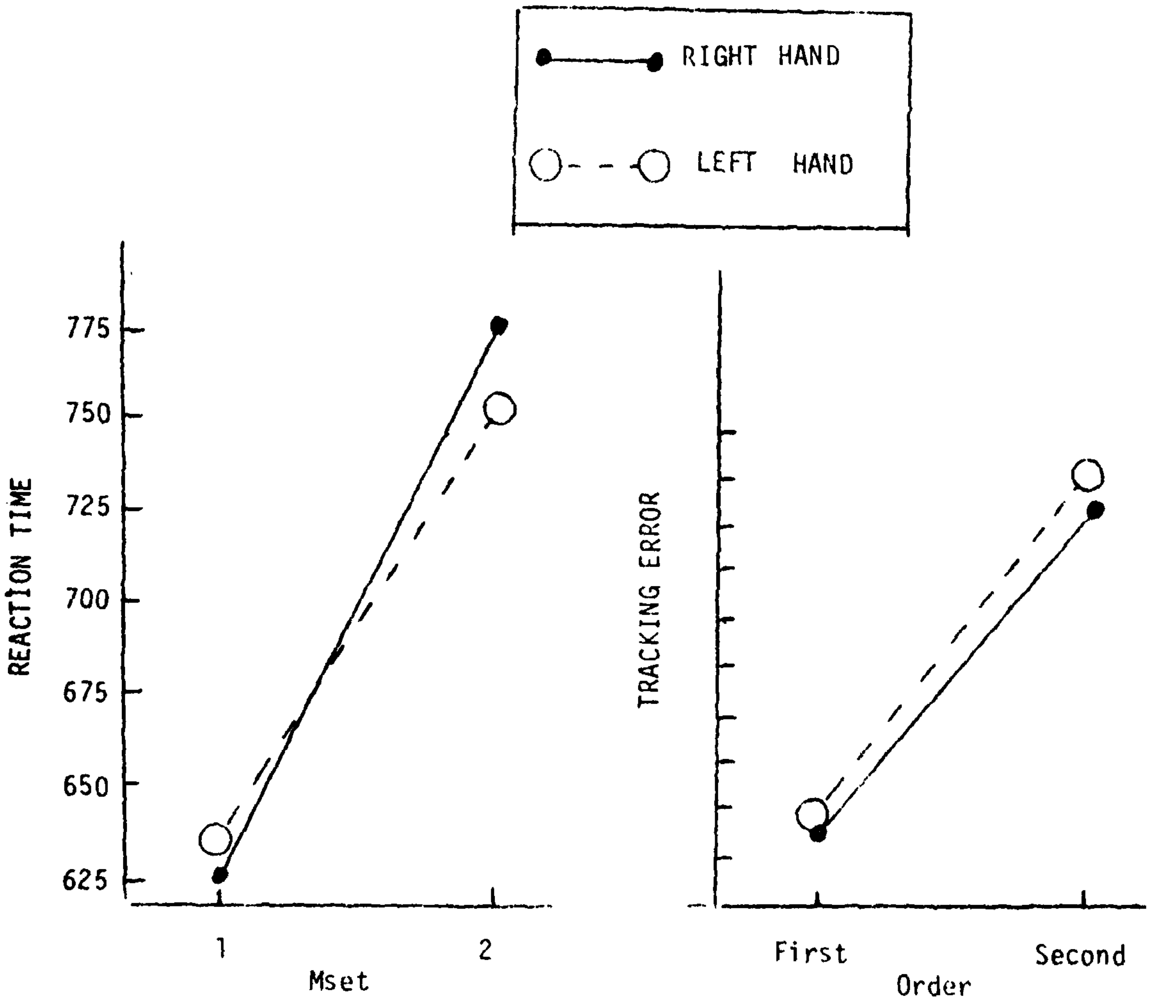


FIGURE 2: *Single task performance on memory search task (left) and tracking task (right).*

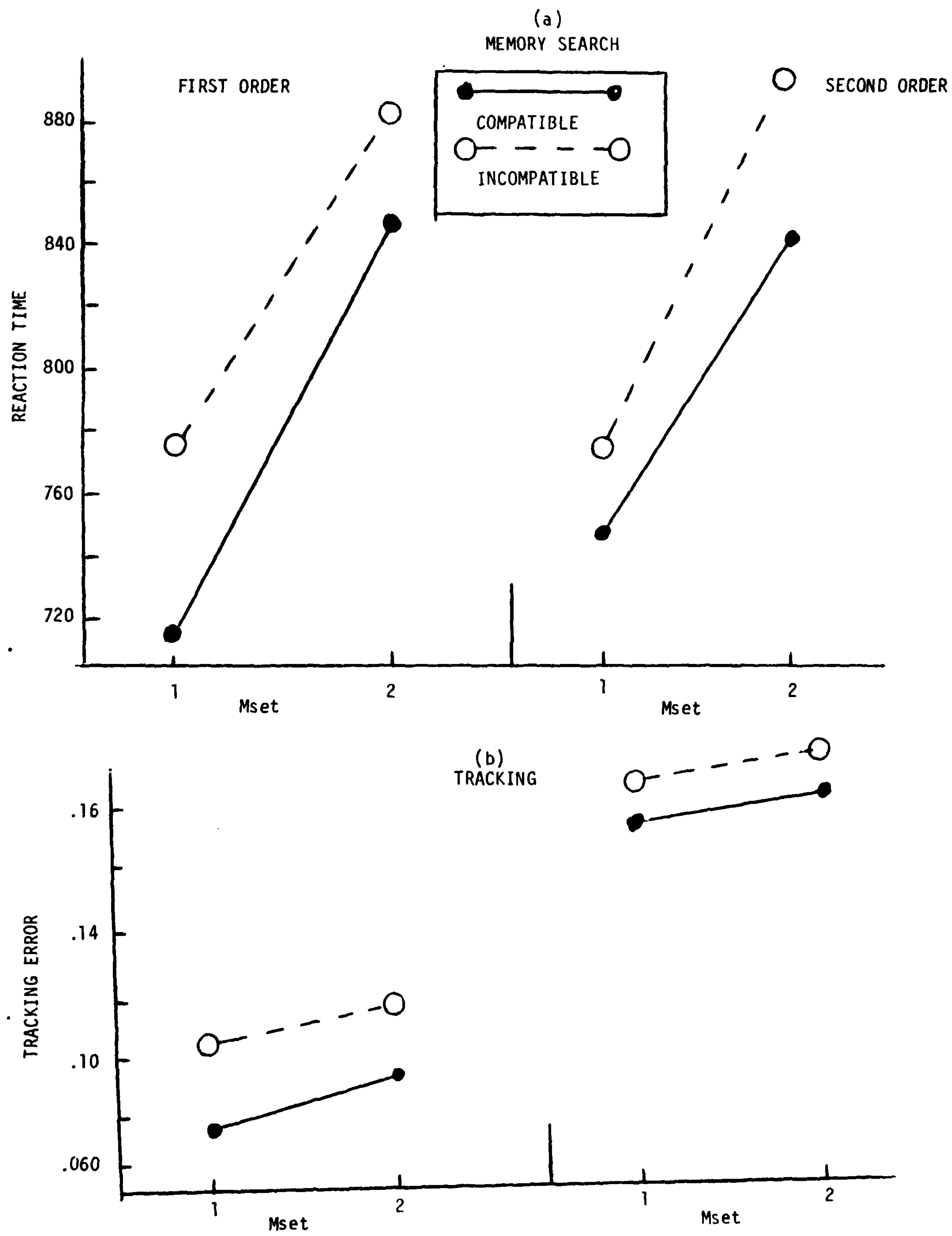


FIGURE 3: Dual task performance in memory search (a) and tracking (b). First order tracking is on the left, second order is on the right.

however failed to strongly influence RT performance in the dual task condition ($F = 3.28$, $p = .10$). However, a marginally reliable 3-way interaction between compatibility, tracking and RT difficulty ($F_{1,9} = 4.62$, $p = .06$) suggested that when tracking order was low, increasing memory set size reduced the compatibility difference in reaction time. However, when the tracking order was high, increasing set size had the opposite effect of enhancing the advantage for compatible assignments.

Error rate for the memory task was significantly effected by three variables. There were more errors made in the more difficult RT and tracking conditions ($F_{1,9} = 37.21$, $p < .01$ and $F_{1,9} = 3.46$, $p < .10$, respectively). Also these two variables interacted so that error rate was influenced by RT difficulty at the easy, but not at the difficult level of tracking ($F_{1,9} = 6.81$, $p < .03$). Since these error rates correlated with latency, we are confident that the latency effects were not attributable to a speed-accuracy tradeoff.

When tracking performance was examined the effects were straightforward. Again the compatible condition showed reliably better performance ($F_{1,9} = 4.31$, $p = .06$) (note that this is a reversed effect from what was seen in single task conditions when the left hand tracked more poorly than the right). Tracking performance was also strongly influenced by its own difficulty ($F_{1,9} = 28.91$, $p < .01$) and was disrupted to a lesser extent by increases in memory load of the concurrent task ($F_{1,9} = 6.88$, $p < .02$). There were no interactions between any of the variables on tracking performance.

Finally, an analysis of the mean velocity of the control stick in the tracking task was undertaken to determine if any of the compatibility effects related to response strategy. As anticipated, control velocity increased with tracking order ($F_{1,9} = 28.52$, $p < .01$). However, neither compatibility, nor any interaction with compatibility, exerted any effect on control velocity, suggesting that the locus of the compatibility effect was probably prior to the selection of responses.

Discussion: Experiment 1

The findings of Experiment 1 were relatively straightforward. When the subject performs only one task at a time, and so provides task information directly to foveal vision (and thus directly to both cerebral hemispheres), three characteristics influence performance. (1) Performance deteriorates as the task becomes harder. (2) Performance is generally better with the dominant hand, particularly in a task such as tracking in which that hand is engaged in coordinated analog manipulation. (3) As the task becomes more difficult there is increased demand for the central processing, or computational resources involved. In tracking, this demand is represented by the operation of a more complex internal model for second order control (Wickens, Gill, Kramer, Ross, & Donchin, 1981). In the memory search task the increase in difficulty involves both greater rehearsal demands on working memory to maintain the larger set, and a longer search process to determine if a positive or negative item has been presented. Evidence that this

processing is lateralized is manifest by the greater disruption of single task performance that occurs when the hemisphere controlling the response is the same as that assumed to be engaged in the processing (i.e., the interaction in Figure 2). This is the result proposed in Principle 3.

When the two tasks are time-shared in a manner that prevents both from accessing foveal vision simultaneously the pattern of effects is altered. There is first an overall dual task decrement. It is likely that a large portion of this decline was the result of peripheral interference--the necessity of scanning--since the two tasks, verbal and spatial, should normally be time-shared quite efficiently as predicted by Principle 2. In the dual task conditions, depending upon where the subject fixates, information from either one or the other task must access peripheral vision. Under one display condition, the two tasks were oriented such that the peripheral task would be provided direct access to the processing hemisphere--a compatible arrangement. Under the other condition, the access was indirect--an incompatible configuration. The results clearly indicated that the magnitude of the dual task decrement was greatly enhanced for incompatible conditions and was reduced for compatible. This effect was most pronounced for the RT task, but it was observable as well for tracking. That is, tracking performance was actually better with the left than right hand under these dual task conditions despite the fact that (a) single task tracking is worse for the left than the right hand and (b) there is within hemispheric resource competition (Principle 2). Of course, the latter factor is not relevant in dual task conditions because a full load is placed on both hemispheres no matter what hand assignment is employed.

Thus the advantage to the compatible assignment may be attributable jointly to the task hemispheric integrity achieved from processing to response (Principle 4), as obtained by Wickens and Sandry. and to the direct access of encoding (Principle 1). The particular benefits of direct access were in evidence because the magnitude of the effect reported here was considerably larger than that reported by Wickens and Sandry in which display location was equally lateralized for both tasks (one was displayed above the other).

Two other characteristics of the results are of note. First, the absence of any strong effects of the difficulty of one variable on performance of the other is consistent with the assumption that functionally separate processing resources were employed (Principle 2). Tracking order did not reliably effect RT, nor did it effect the magnitude of the dual task decrements when these were calculated for the tracking task by substracting single from dual task error. Memory load did have a consistent effect on tracking performance ($p < .02$), but the increase in RT due to increasing memory load was no greater in dual task than in single task conditions. The second characteristic of note was the absence of any large interactions between compatibility and other factors of task difficulty. This "additivity" would seem to suggest that the two variables of task difficulty--tracking order and memory load influence different stages of processing than those which

benefit from direct access and task hemispheric integrity. The applied implications of this additivity are comforting because it suggests that the display principle indicated by direct access is general and is not one dependent exclusively on a particular level of difficulty.

The present experiment did not address the strategies of performance by which the task was performed. In particular, the subjects' direction of gaze was not controlled. As noted ealier, this was not done, in part to allow greater generality to real world environments. We can be certain however that some strategies were not employed. Since it is impossible to resolve letters while fixating on the tracking display, subjects could not have focussed exclusively on tracking. However, whether subjects focussed on the continuous tracking display and switched rapidly when the appearance of a memory stimulus was detected, or whether they focussed continuously on or near the memory display, while tracking parafoveally cannot be determined from the present data. Experiment 2 was designed to answer these questions more precisely.

Experiment 2

In Experiment 2, two different conditions of task priority were imposed, one emphasizing performance of the tracking task, the other performance of the memory search task. These priority instructions were reinforced by recommendations regarding fixation. In the tracking emphasis conditions, subjects were instructed to fixate the tracking display during intervals between the memory stimuli. In the memory emphasis condition, they were instructed to fixate the memory display with tracking carried out parafoveally.

Method: Experment 2

The same subjects who participated in Experiment 1 were employed in Experiment 2. In this experiment all characteristics of the task were identical to Experiment 1, except for the instructions as described above. In addition, only the most difficult condition (second order tracking, memory set = 2) was performed. Subjects were given 24 trials on a single session. These trials consisted of six replications each of the four conditions created by combining two levels of display compatibility with two levels of task emphasis. No single task data were collected.

Results: Experiment 2

Figure 4 presents the data from Experiment 2 in a performance operating characteristic, or POC space (Navon & Gopher, 1979; Wickens, 1981). Each point in the space represents a dual task condition, with the level of tracking performance equal to the projection of the point on the horizontal axis, and the level of memory task performance (RT) equal to the projection on the vertical axis. Performance on both axes is inverted so that good performance (low error and low reaction time) is represented toward the upper right of the space. A bias toward the memory task is indicated by a shift to the upper left in the space; a

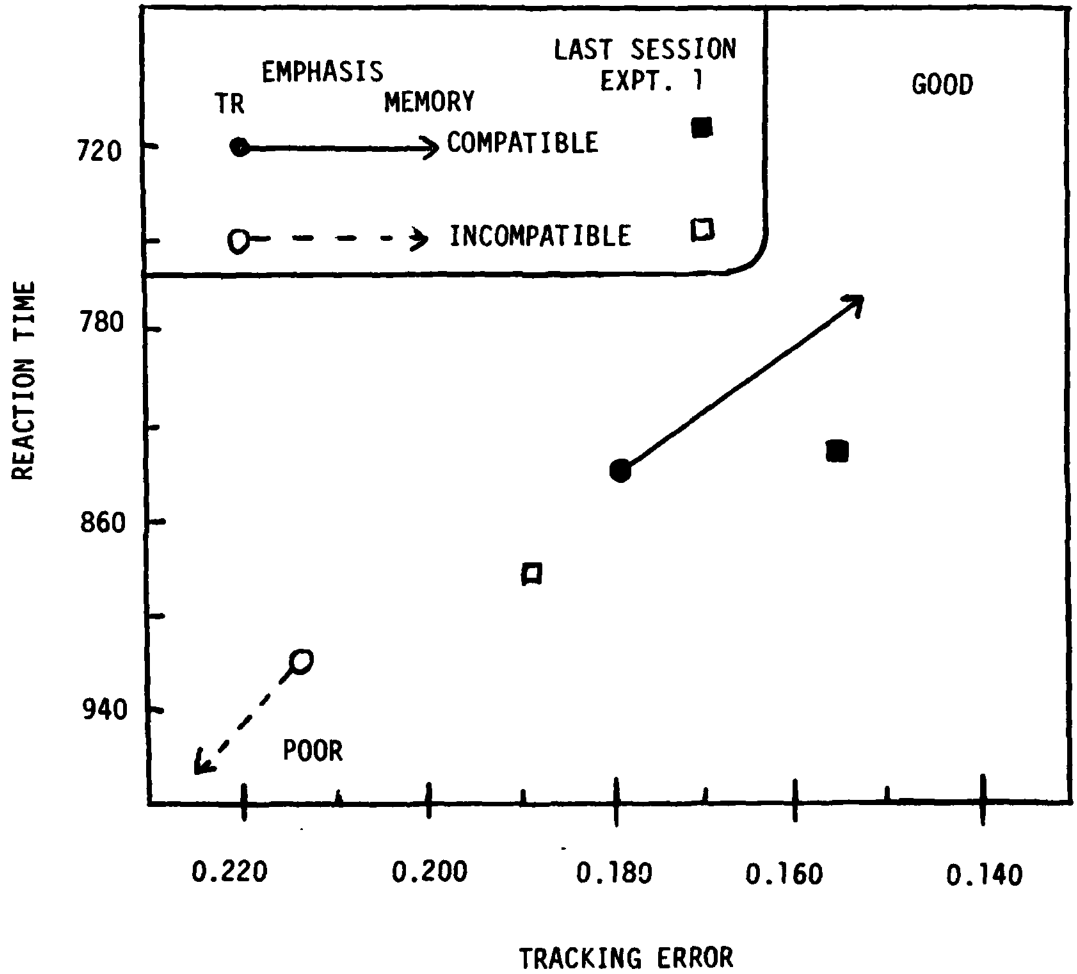


FIGURE 4: Dual task performance in Experiment 2 represented in Performance Operating Characteristic (POC) space. Arrow points from tracking emphasis to memory emphasis conditions. Goood performance on both tasks is to the upper right, poor performance to the lower left.

bias toward tracking by a shift toward the lower right. Each vector represents performance with a different display type. The arrow on each vector indicates the change in dual task performance when emphasis is from the tracking task to the memory task. Finally, the two single squares represent the joint level of performance that was obtained on the final session of Experiment 1 for the two conditions.

Figure 4 indicates that the pronounced effect of compatibility observed in Experiment 1 is equally present in Experiment 2. Both data points for the compatible condition lie far closer to the upper right portion of the POC space than for the incompatible. The data for each dependent variable were submitted to a 2(empahsis) x 2(condition) x 6(replication) ANOVA and here again the main effect of compatibility was significant for both dependent variables (tracking, $F_{1,9} = 26.6$, $p = .001$; RT: $F_{1,9} = 22.6$, $p = .01$). The effect of task emphasis however was less consistent and unexpected. One would expect that shifting emphasis to the memory task (the direction of the arrows) would move the points toward the memory axis. Yet instead, emphasizing memory improved performance on both tasks when the displays were compatible and deteriorated performance on both when the displays were incompatibly arranged. These trends counteracted each other in such a manner that the main effect of emphasis was not significant for either dependent variables ($p > .10$ in both cases), but the emphasis x compatibility interaction was quite significant for both (tracking; $F_{1,9} = 21.2$; $p < .01$; reaction time; $F_{1,9} = 21.03$, $p < .01$).

The error rate on the memory search task showed only one reliable effect: a main effect of compatibility which was observed in the same direction as latency, i.e., higher errors in the less compatible condition.

Discussion: Experiment 2

The absence of a main effect of task emphasis was somewhat surprising since most research in which emphasis instructions have been employed demonstrate a consistent shift on at least one, if not both of the tasks in the dual task combination (Wickens, 1981); however, considering the nature of the two tasks involved and the layout employed there exist at least two plausible accounts for these results, one in terms of a shift in operator strategies, the other in terms of a "right task advantage."

With regard to the first account, we propose that two strategies can be adopted. Because with the display separation used here, the memory stimuli could not be read in peripheral vision when the instructions emphasized tracking, a discrete attention switching strategy is necessary. Subjects must fixate the tracking display, and when their peripheral vision detects the appearance of the memory stimulus, a saccade is executed. When, on the other hand, the memory task is emphasized and fixated it is possible to employ a parallel processing strategy. This is because tracking in parafoveal vision is not only possible but relatively efficient at the small angle of eccentricity used here (4°) (Levison, Elkind, & Ward, 1971). Several

investigators have called attention to the ability of operators to extract the velocity information necessary in second order tracking, from parafoveal locations (Bermundez et al., 1979; Kelly, 1968).

The use of the two strategies predicts the interaction with task emphasis as follows. When the tracking task is emphasized it gains access to foveal vision. The subject must then either scan left or scan right when the memory stimulus occurs in order to process that information in foveal vision as well. Thus since most processing of both tasks is done foveally there is little lateralized perceptual processing with either display, and so the two display conditions do not differ greatly. This is why the two tracking emphases conditions lie closer together in the POC space of Figure 4. What difference there is, in favor of the compatible display is probably attributable to the direct access to the left visual field of the tracking display at the points when the memory display is fixated, and to ongoing effects of processing-response compatibility--the task hemispheric integrity effect obtained by Wickens and Sandry (in press) and Wickens, Mountford, and Schreiner (1981).

When however, the memory task is emphasized and fixated, parallel processing is now possible since the tracking display can be perceived peripherally. Yet the effectiveness of this parallel processing is strongly influenced by the direct access principle. When direct access for the tracking is possible in the left visual field, there is a benefit to both tasks. In the incompatible assignment, when direct access is now violated and tracking must be performed parafoveally in the right visual field, the incompatibility leads to a pronounced deterioration of performance.

The question of why tracking actually <u>improves</u> when it is shifted out of foveal vision to the left visual field in the compatible condition is not as readily answered. One possibility is that the advantage to the memory task of providing it exclusive foveal vision was great enough to allow the resources freed by the memory task to be reallocated to tracking. A related explanation concerns what Navon and Gopher (1979) have referred to as a "cost of concurrence": an added resource cost that occurs when the operator must supervise and manage a time-sharing situation, and which must be extracted from resources available to one or both of the tasks involved. We propose that this cost is greater when tracking is emphasized, and that the cost is also extracted from tracking performance. There are two reasons for the greater cost in the tracking emphasis condition: (1) The visual system must engage in monitoring, and scanning behavior which involves some executive functioning. This need not occur when the memory task is fixated and parallel processing occurs. (2) When tracking is foveal, information travels to both hemispheres. Therefore there is possibly some disruption of left hemispheric processing of the verbal stimuli, due to the arrival of this spatial information which imposes added "housekeeping" chores required to maintain integrity. Both of these costs are removed when tracking is moved into the compatible left periphery.

The second possible interpretation of the emphasis by display interaction is proposed in terms of an advantage for emphasis of tasks on the right. It is possible to reconsider the priority manipulation in terms of whether the task on the right or the left is emphasized, independent of which task it is. In this case, if the vector on the lower left of Figure 4 were reversed in direction it would always point toward the condition in which the right hand task was emphasized. Then we would see that performance on both tasks improves whenever the subject emphasizes the task displayed and controlled to the right. It is not immediately clear why this should be the case, however, unless tasks to the left, non-dominant side are relatively more able to be performed at an automated, non-conscious level. Some research by Peters (1977; 1981) suggests that this might be the case. Peters found that subjects could time-share a self-generated and a metronome-paced tapping task better when the self-generated task, which he proposed to be more demanding, was performed with the right hand, and the paced tapping task with the left. This advantage he argues results because the left hand is more attuned to processing the more automated task. It is not clear however whether this argument allows us to conclude that the left hand benefits less from the allocation of attention than the right in bi-manual activities. If this is the case, then some of the observed effect could also be explained by the "rightward bias."

General Discussion

Collectively, the two experiments reported here suggest that the combined effects of task-hemispheric integrity of display and control are robust ones in dual task situations. The tasks chosen here--control of first or second order systems and monitoring a communication channel for alpha-numeric information--were more complex than those previously used. The compatibility effect, which was observable in both tasks, was preserved across levels of task difficulty, and changes in task priority. If anything, the magnitude of the effect appeared to increase as the subjects were well practiced (Experiment 2 vs. Experiment 1).

Of course, there will be other factors that should influence the relative location of displays and controls. Most importantly, in aviation, this will depend upon design stereotypes in which right handed control over flight dynamics is prevalent. Furthermore, the standard priorities of "aviate, communicate, and navigate" insure that displays of inner-loop flight parameters will probably always be considered "primary." Yet where such stereotypes are not present, and where concurrent activity may be required. The present results suggest the clearcut advantages of compatible configurations. When the memory task was emphasized in Experiment 2, the incompatible configuration contributed to a 50% increase in tracking error and a 28% increase in response latency.

It is apparent from the analysis of Experiment 2 that the largest direct contributor to compatibility effects is the tracking task since the verbal information used here, and probably in most real world environments will have to be processed foveally. Thus the results bear, not only on the relative placement of verbal and spatial information displays, but also on the optimal placement of subsidiary spatial displays in the periphercy such as "barber poles" or "streaming" used to indicate rate of change information (Bermundez, Harris, & Schwank, 1979). While these could probably assist performance anywhere, the present data, coupled with those of Levison et al. (1971) and Casey et al. (1977) indicate that their greatest benefit will be realized if placed to the left.

Finally, the present data have important implications for the effects of instructions on time-sharing strategy (Gopher & Brickman, 1981; Damos & Smist, 1980). A major element underlying resource theory is that subjects can allocate attention differentially to different tasks and that there are certain "optimal" allocation policies that will mamimize a joint index of performance (Navon & Gopher, 1979). The current data suggest that the priority allocations may have unexpected effects if the time-sharing strategy that must be employed (scanning versus parallel processing) changes as a function of which task is emphasized.

The importance of allocation strategy is further highlighted by comparing performance on the final session in Experiment 1 (indicated by the boxes in Figure 4) with performance in Experiment 2. We may think of Experiment 1 performance as that adopted by subjects spontaneously, when left to their own devices. In Figure 4 we see that performance on <u>both</u> tasks actually improved from this spontaneous level when subjects were instructed, in essence, to track in the left visual field. Subjects were apparently unaware of the benefit when this direct access provided them, and so failed to perform optimally on their own.

In conclusion, few of the burgeoning number of studies of hemispheric laterality have suggested relevance to the applied world of systems design. The present results however do provide such relevance. The tasks employed bore a reasonable resemblance to tasks an operator must perform, and the effects were both robust and stable across experimental manipulations. We believe that the critical factor that led to the emergence of the laterality effect is the heavy time-sharing load placed on the subjects. When this load is imposed, then the optimum configuration of displays and controls becomes of paramount importance.

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Human Factors Laboratory
Virginia Polytechnical Institute
and State University
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Blacksburg, VA 24061

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Information Sciences Division
Bolt Beranek & Newman, Inc.
50 Moulton Street
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Bolt Beranek & Newman
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Cambridge, MA 02138

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University of Southern California
Behavioral Technology Laboratory
3716 S. Hope Street
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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91125

Dr. Marshall Farr
Office of Naval Research
Code 442
800 N. Quincy St.
Arlington, VA 2217

Dr. Earl Hunt
University of Washington
Department of Psychology
Seattle, WA 98105